SIXTY YEARS
OF DISCOVERY
1947-2007

Brookhaven National Laboratory

CLIMATE CHANGE

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Environmental Sciences Department

October 19, 2007

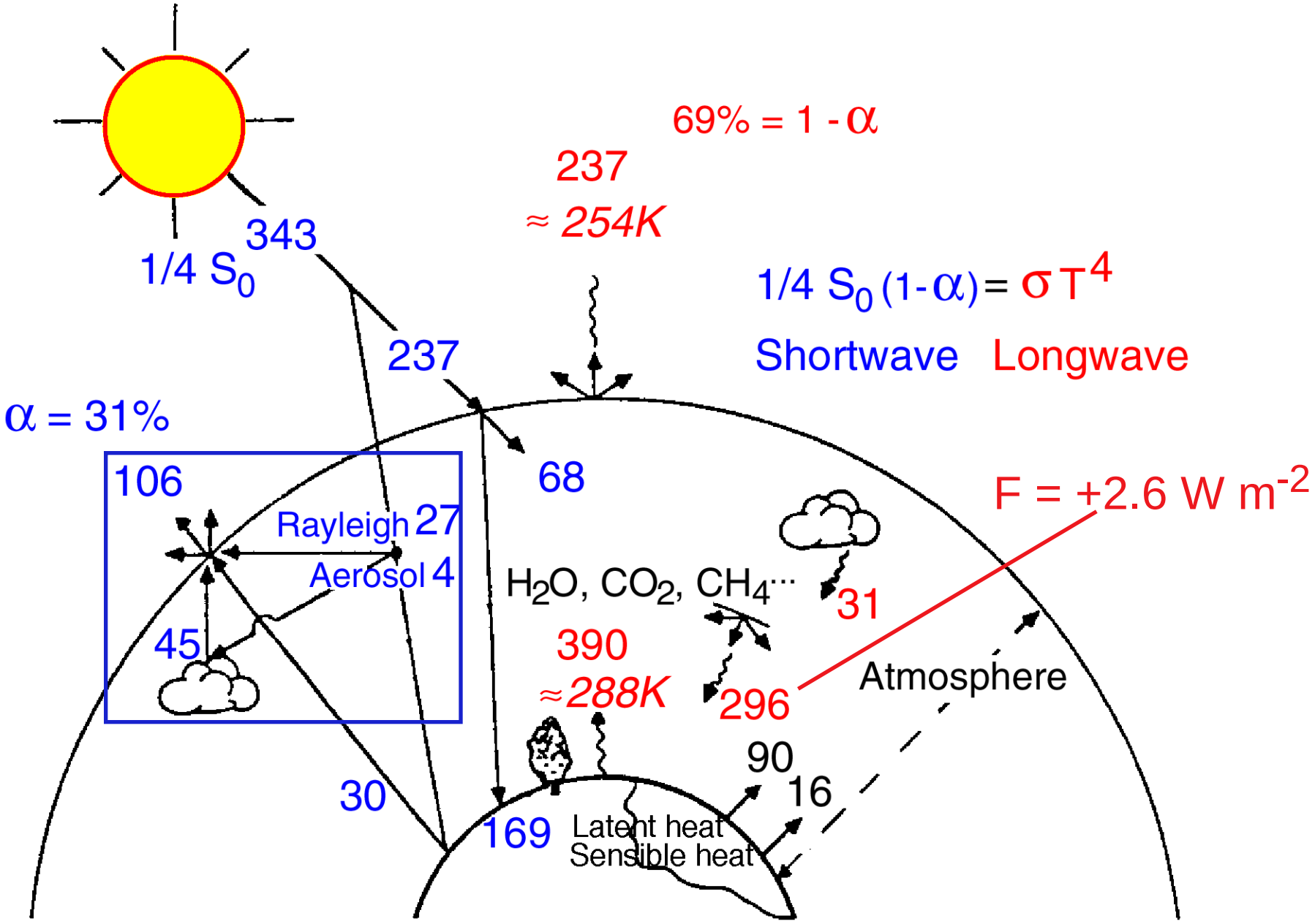
http://www.ecd.bnl.gov/steve

OUTLINE

- Earth's energy balance
  - Perturbations
  - Key questions
  - Influence of aerosols
- Climate research at BNL
  - Atmospheric Science Program ASP
  - Atmospheric Radiation Measurement ARM
- Looking to the future

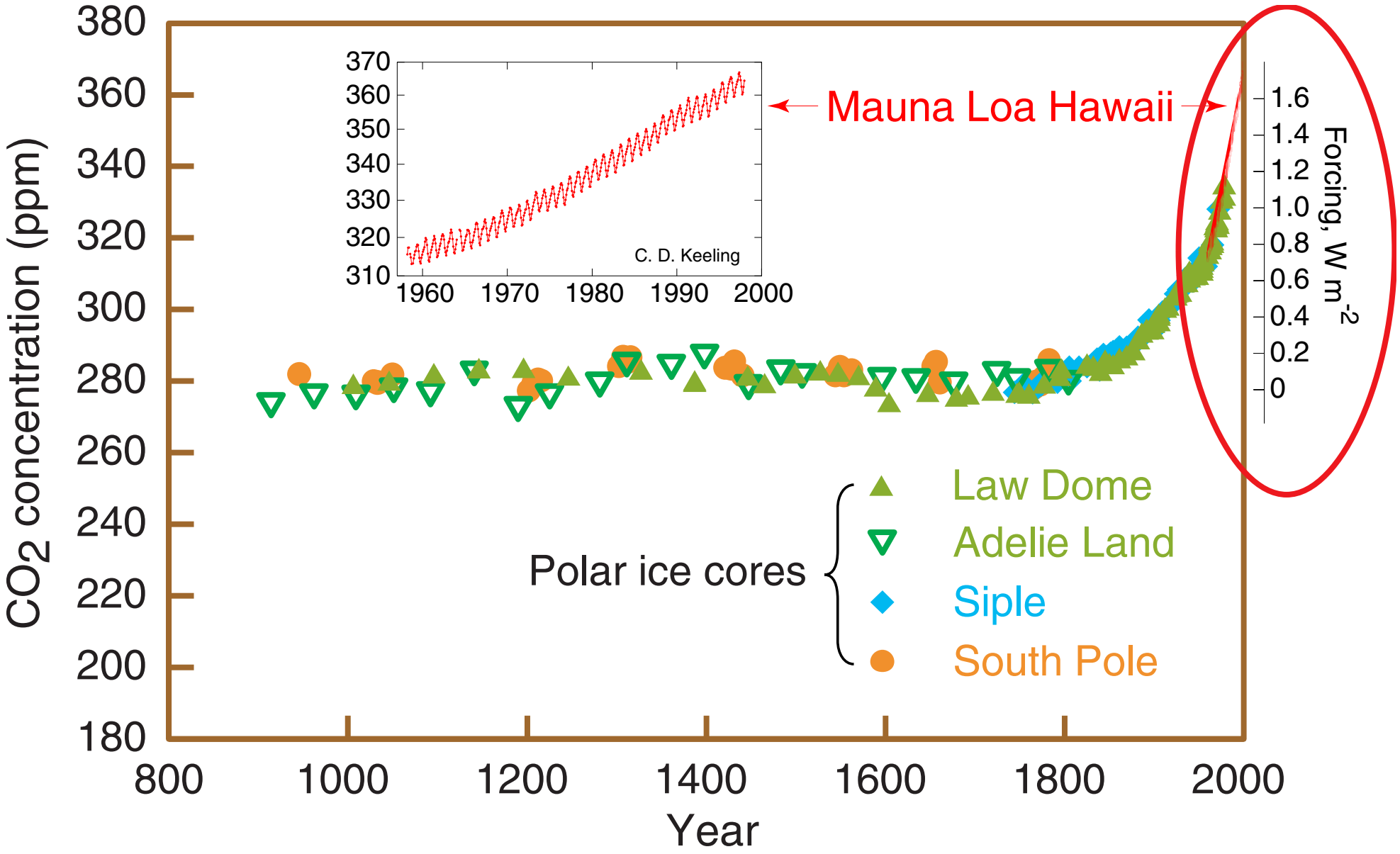
GLOBAL ENERGY BALANCE

Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

ATMOSPHERIC CARBON DIOXIDE IS INCREASING



Global carbon dioxide concentration and infrared radiative forcing over the last thousand years

RADIATIVE FORCING

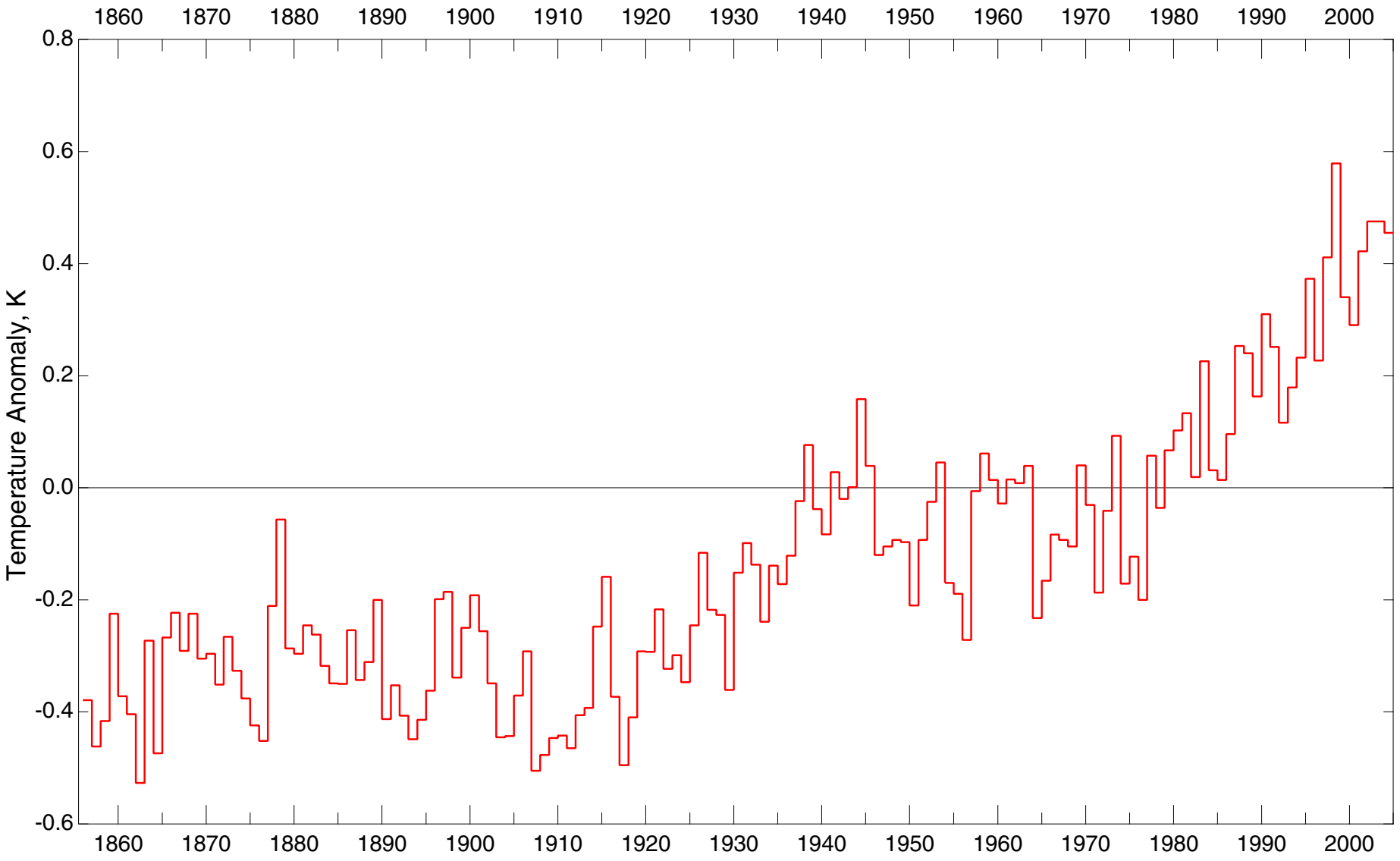
A ***change*** in a radiative flux term in Earth's radiation budget, ΔF, W m^{-2}.

Working hypothesis:

On a global basis radiative forcings are additive and fungible.

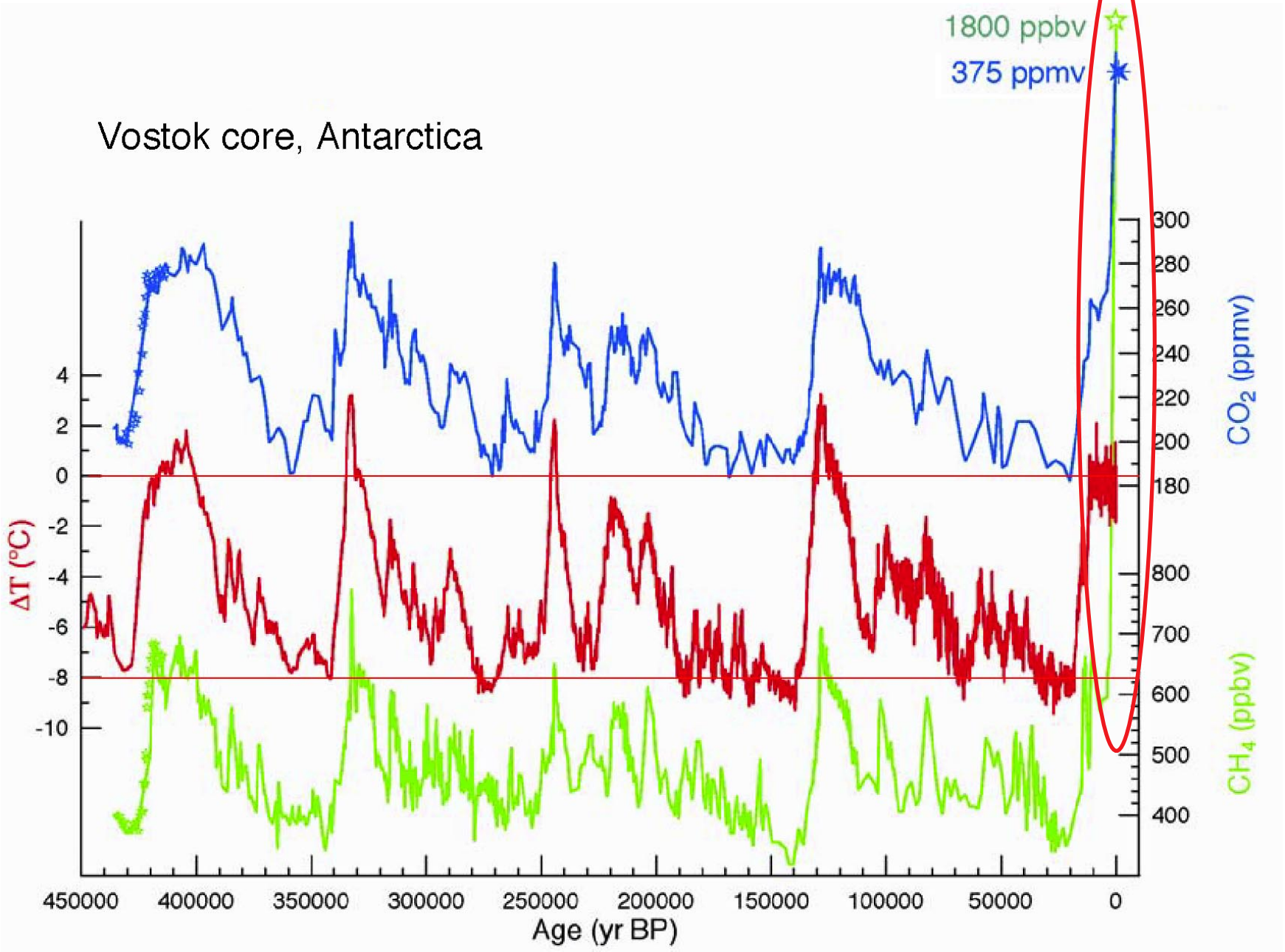
- This hypothesis is fundamental to the radiative forcing concept.
- This hypothesis underlies much of the assessment of climate change over the industrial period.

CHANGE IN GLOBAL MEAN SURFACE TEMPERATURE 1855-2004



Climate Research Unit, University of East Anglia, UK

GREENHOUSE GASES AND TEMPERATURE OVER 450,000 YEARS



Modified from Petit et al., Nature, 1999

CLIMATE RESPONSE

The ***change*** in global and annual mean temperature, ΔT, K, resulting from a given radiative forcing.

Working hypothesis:

The change in global mean temperature is proportional to the forcing, but independent of its nature and spatial distribution.

$$\Delta T = \lambda \, \Delta F$$

CLIMATE SENSITIVITY

The ***change*** in global and annual mean temperature per unit forcing, λ, K/(W m^{-2}),

$$\lambda = \Delta T/\Delta F.$$

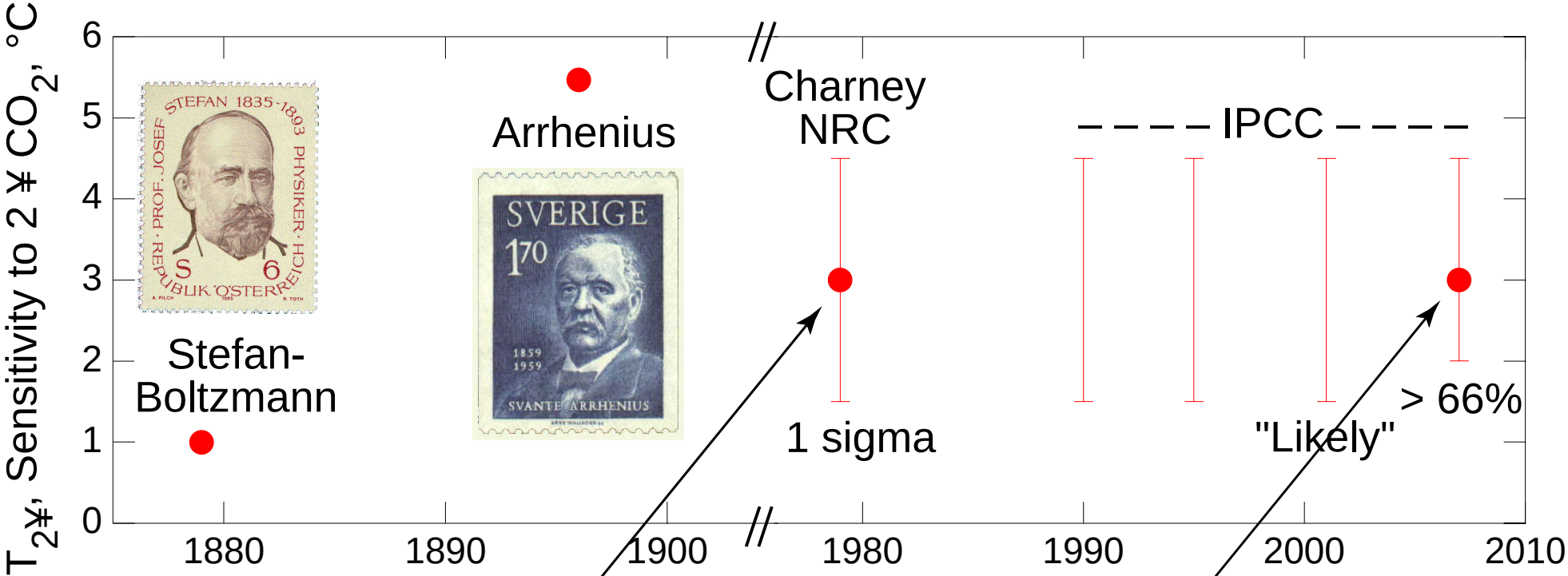
Climate sensitivity is not known and is the objective of much current research on climate change.

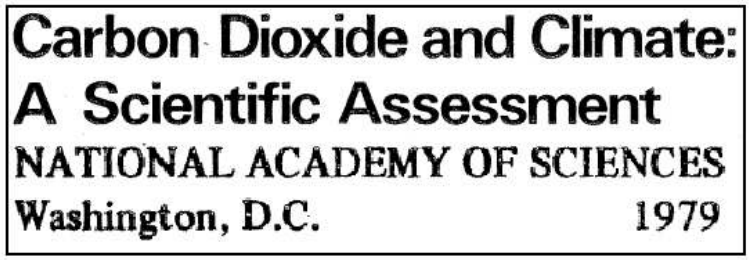
Climate sensitivity is often expressed as the temperature for doubled CO_2 concentration $\Delta T_{2\times}$.

$$\Delta T_{2\times} = \lambda \, \Delta F_{2\times}$$

CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

Estimates of central value and uncertainty range from major national and international assessments





Despite extensive research, climate sensitivity remains ***highly uncertain***.

IMPLICATIONS OF UNCERTAINTY IN CLIMATE SENSITIVITY

Uncertainty in climate sensitivity translates directly into . . .

- Uncertainty in the amount of ***incremental atmospheric*** $\mathbf{CO_2}$ that would result in a given increase in global mean surface temperature.
- Uncertainty in the amount of ***fossil fuel carbon*** that can be combusted consonant with a given climate effect.

At present this uncertainty is about a factor of 3.

KEY APPROACHES TO DETERMINING CLIMATE SENSITIVITY

- Paleoclimate studies.
- Empirical, from climate change over the instrumental record.
- Climate modeling.

Climate models evaluated by comparison with observations are essential to informed decision making.

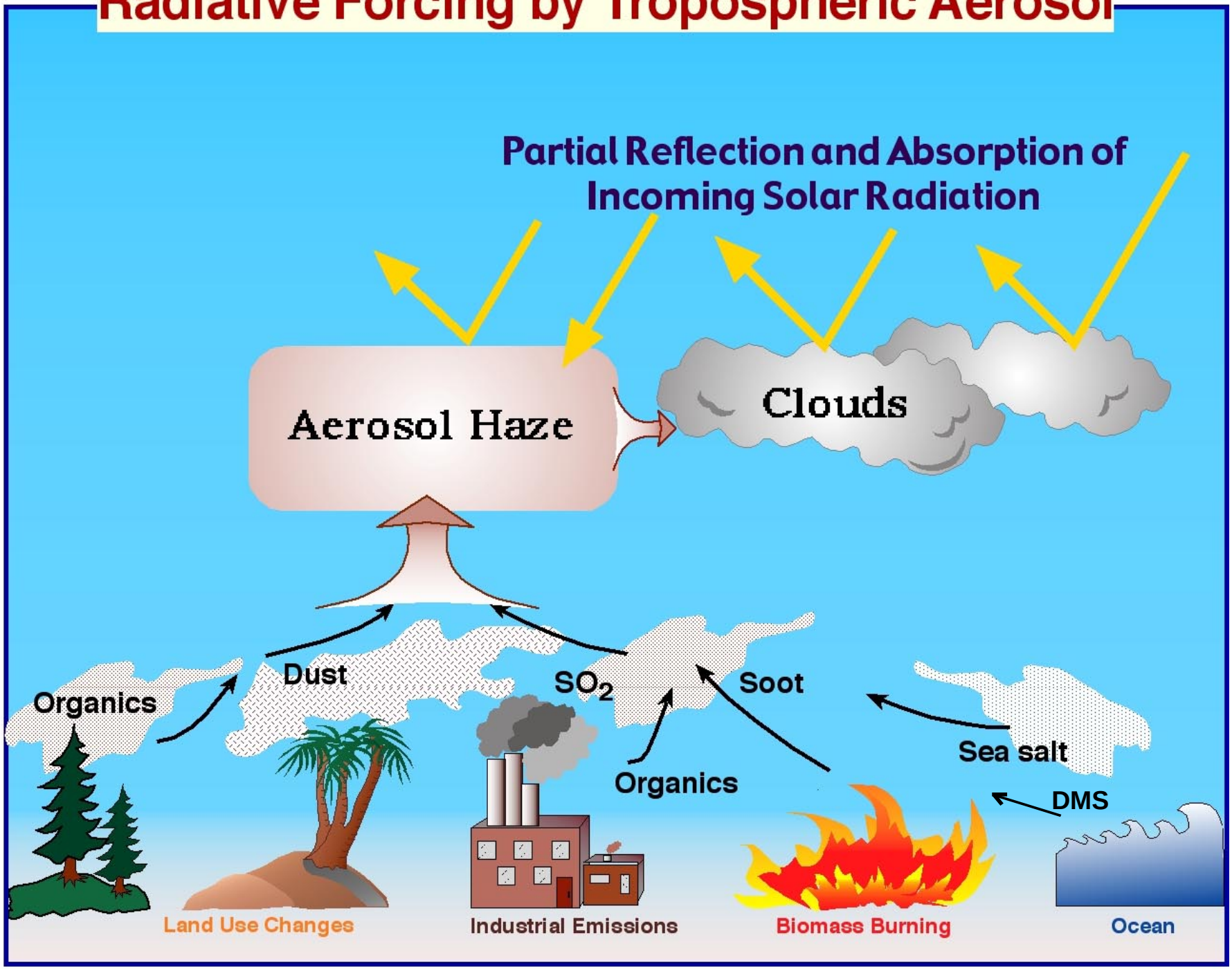
IMPORTANCE OF KNOWLEDGE OF CLIMATE TO INFORMED DECISION MAKING

- The half life of incremental atmospheric CO_2 is about 100 years.
- The expected life of a new coal-fired power plant is 50 to 75 years.

Actions taken today will have long-lasting effects.

Early knowledge of climate sensitivity can result in huge averted costs.

Radiative Forcing by Tropospheric Aerosol

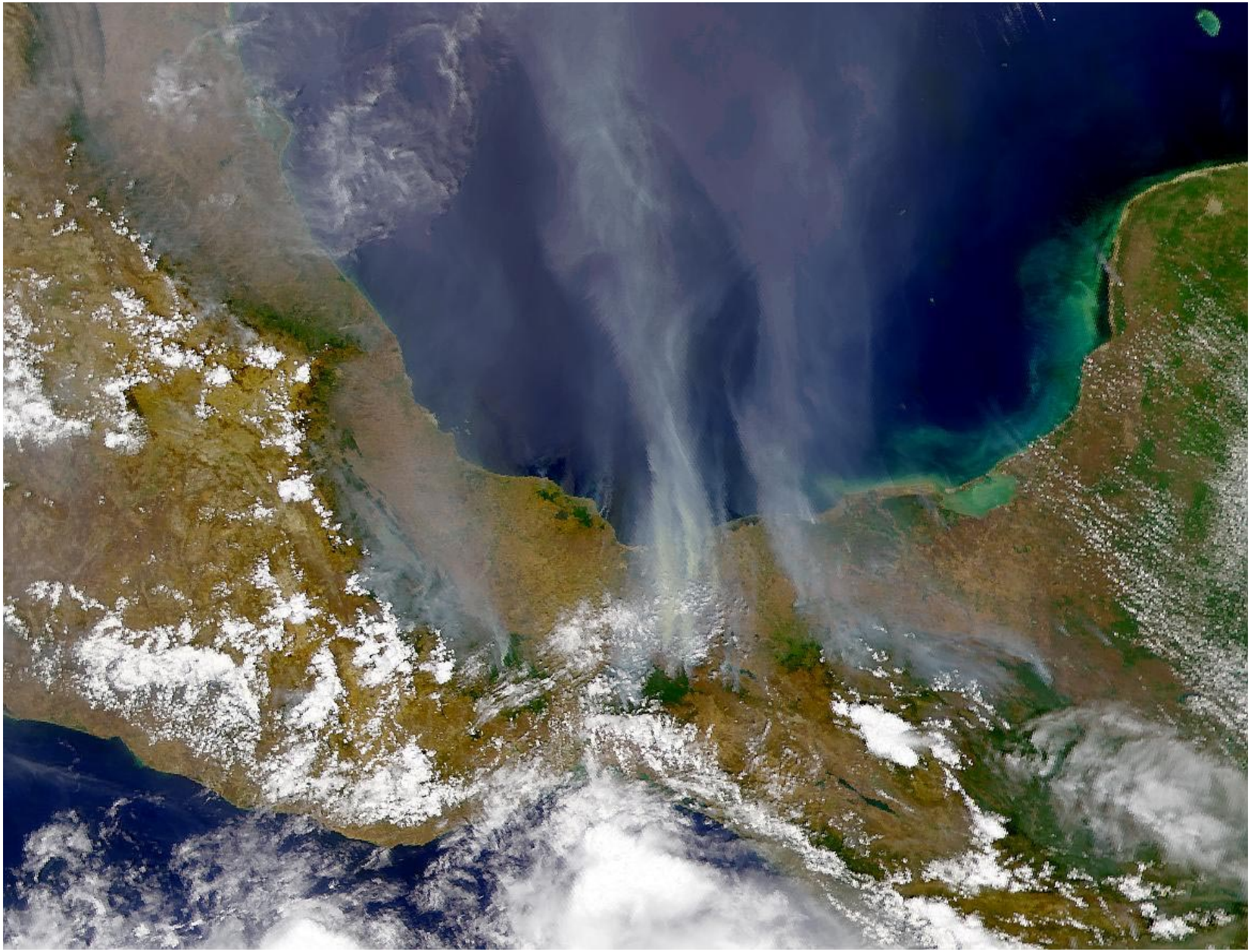


AEROSOL IN MEXICO CITY BASIN

AEROSOL IN MEXICO CITY BASIN

Mexico City is a wonderful place to study aerosol properties and evolution.

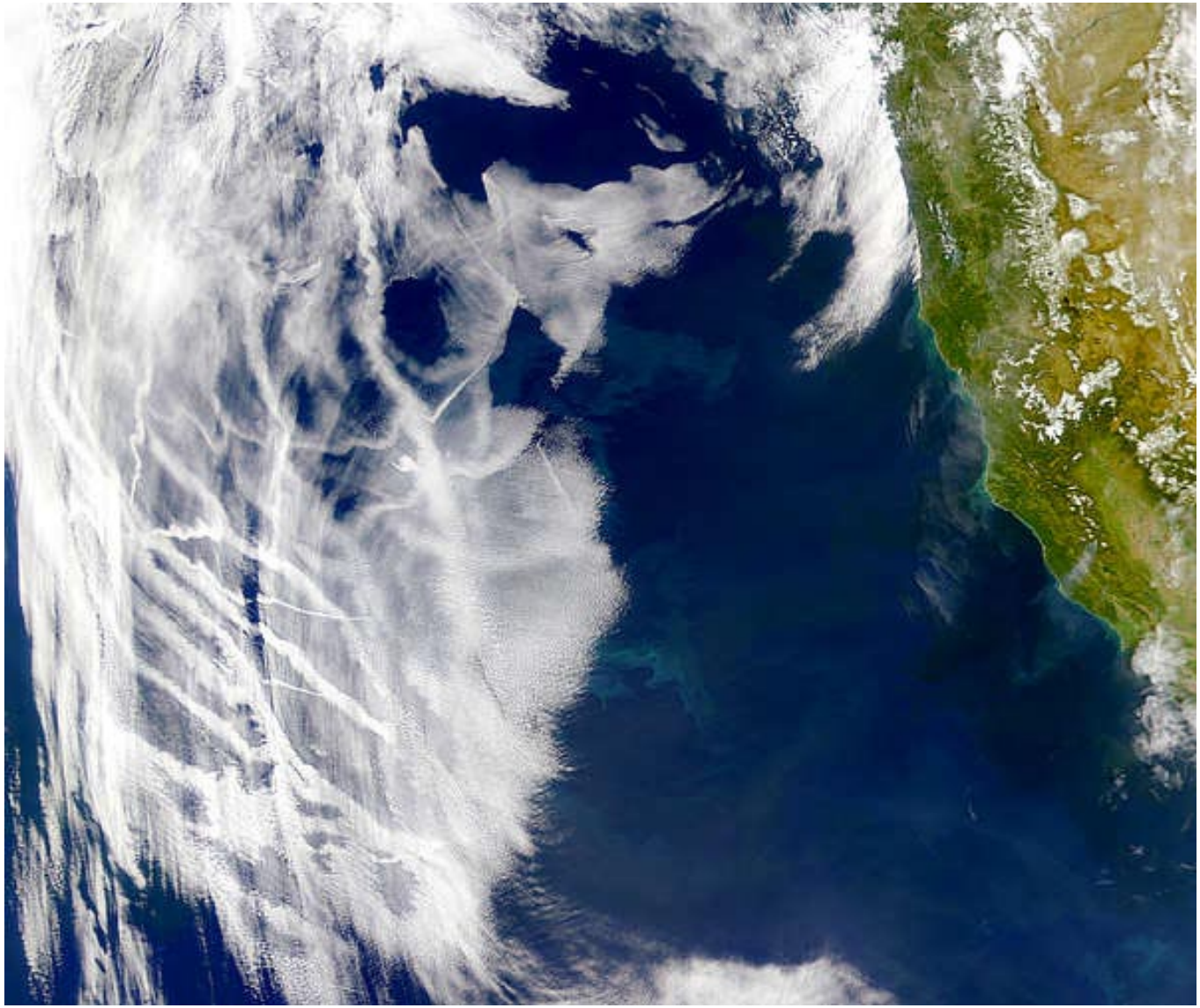
AEROSOLS AS SEEN FROM SPACE



Fire plumes from southern Mexico transported north into Gulf of Mexico.

CLOUD BRIGHTENING BY SHIP TRACKS

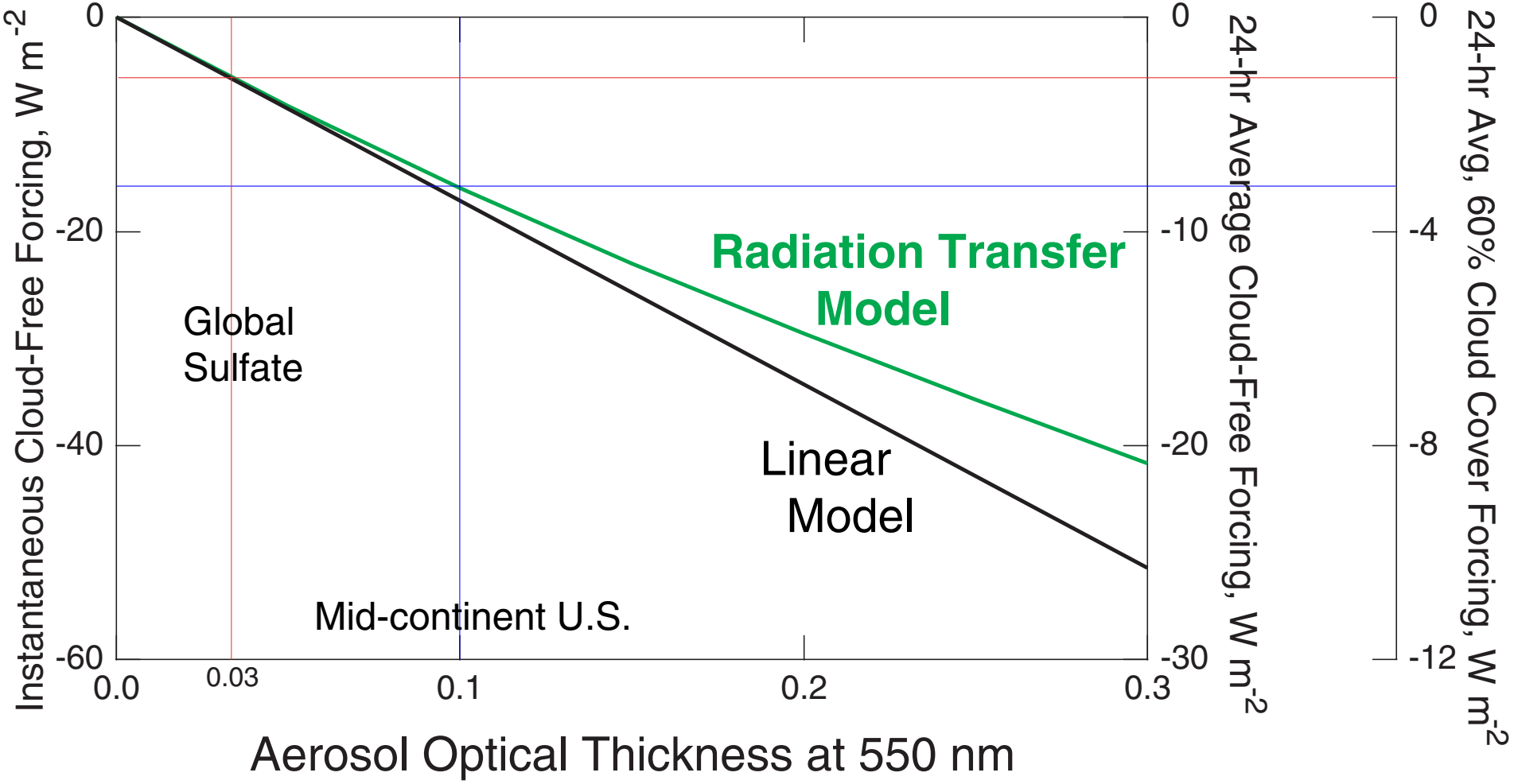
Satellite photo off California coast



Aerosols from ship emissions enhance reflectivity of marine stratus.

ESTIMATES OF AEROSOL DIRECT FORCING

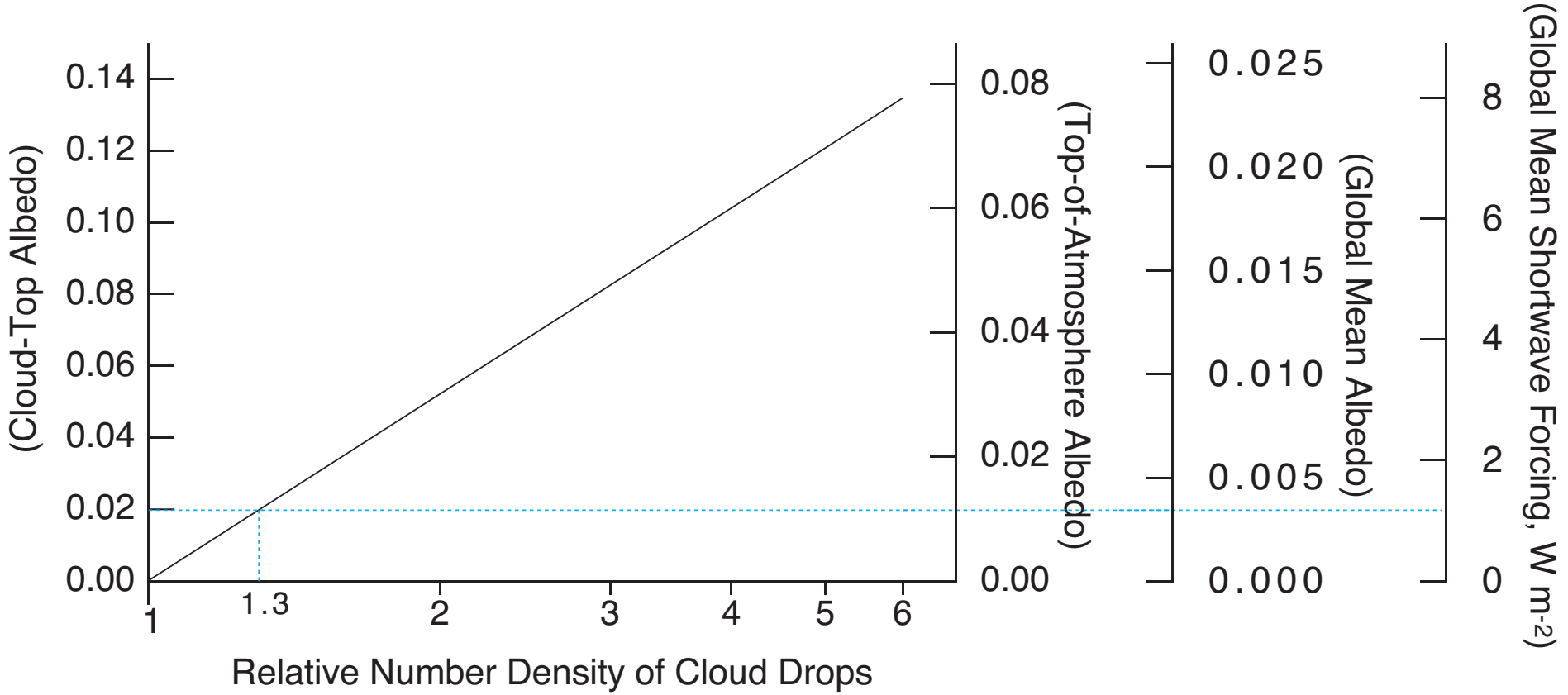
By linear model and by radiation transfer modeling



Global average sulfate optical thickness is 0.03: ***1 W m^{-2} cooling.***

In ***continental U. S.*** typical aerosol optical thickness is 0.1: ***3 W m^{-2} cooling.***

SENSITIVITY OF ALBEDO AND FORCING TO CLOUD DROP CONCENTRATION



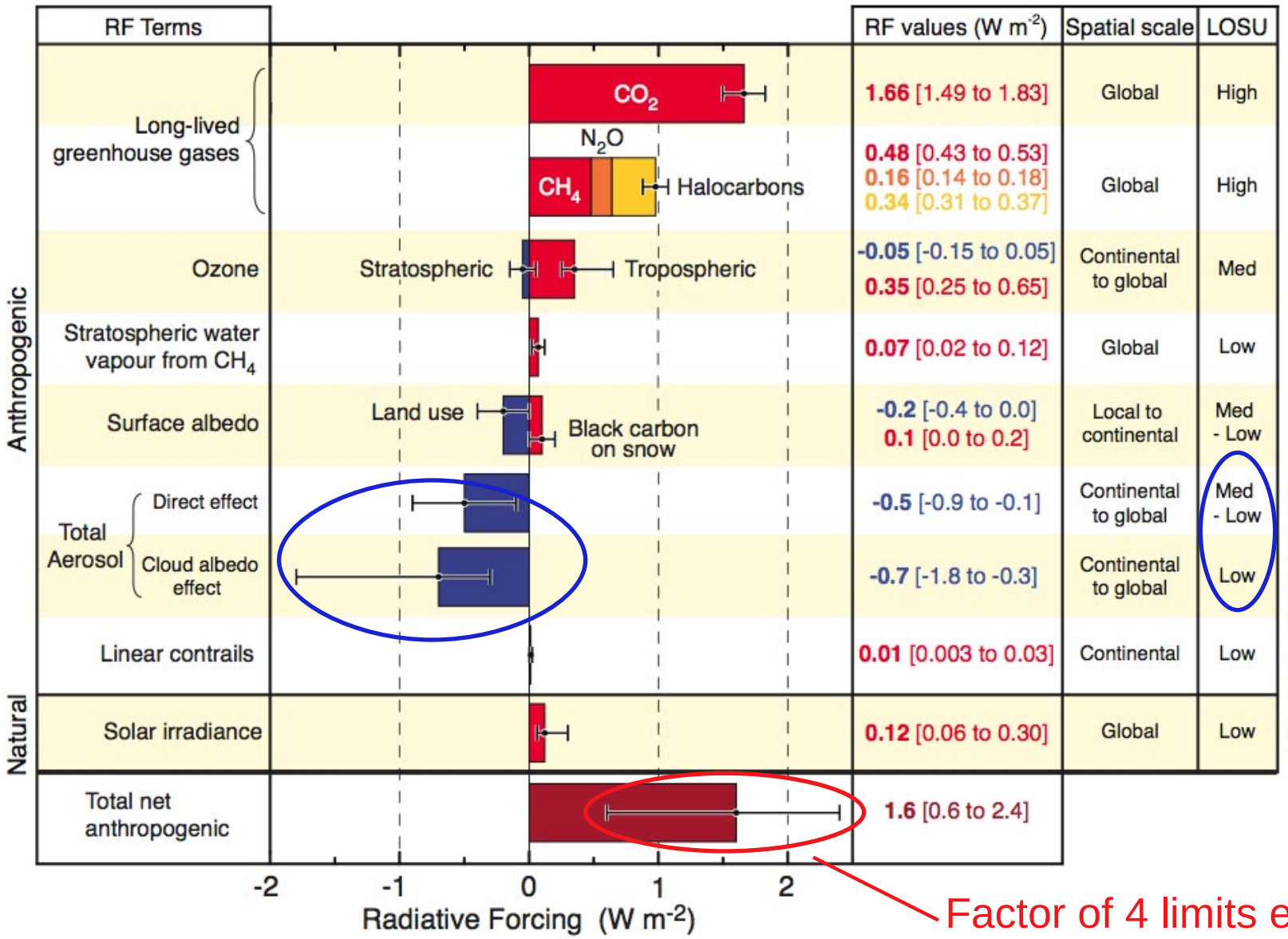
Schwartz and Slingo (1996)

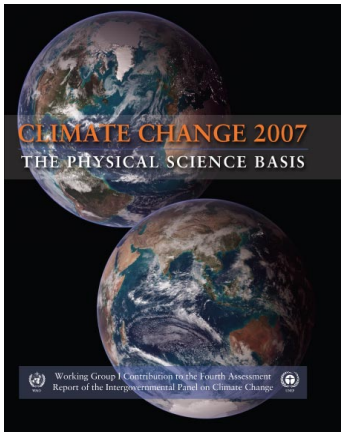
Indirect forcing is highly sensitive to perturbations in cloud drop concentration.

A 30% increase in cloud drop concentration results in a forcing of ~1 W m^{-2}.

GLOBAL-MEAN RADIATIVE FORCINGS (RF)

Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)

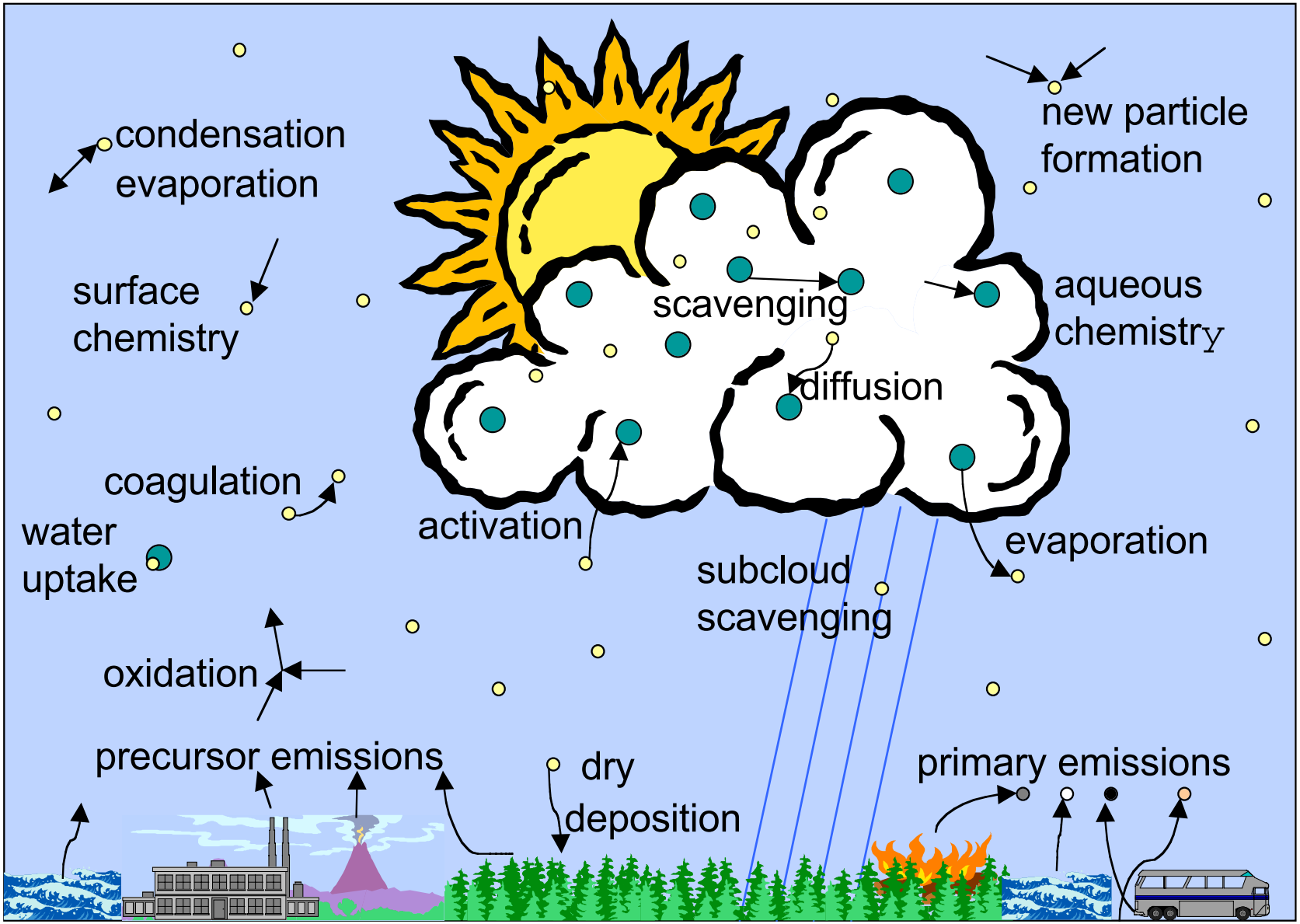




Factor of 4 limits empirical inferences and model evaluation.

LOSU denotes level of scientific understanding.

AEROSOL PROCESSES THAT MUST BE UNDERSTOOD AND REPRESENTED IN MODELS



Ghan and Schwartz, Bull. Amer. Meterol. Soc., 2007

CLIMATE RESEARCH AT BNL

Two major DOE programs

Atmospheric Science Program

Radiative forcing by atmospheric aerosols

Field programs, instrument development, modeling

Chief scientist: Stephen Schwartz

Atmospheric Radiation Measurement Program

Atmospheric radiation and controlling variables, esp. clouds

Measurement, modeling, data management

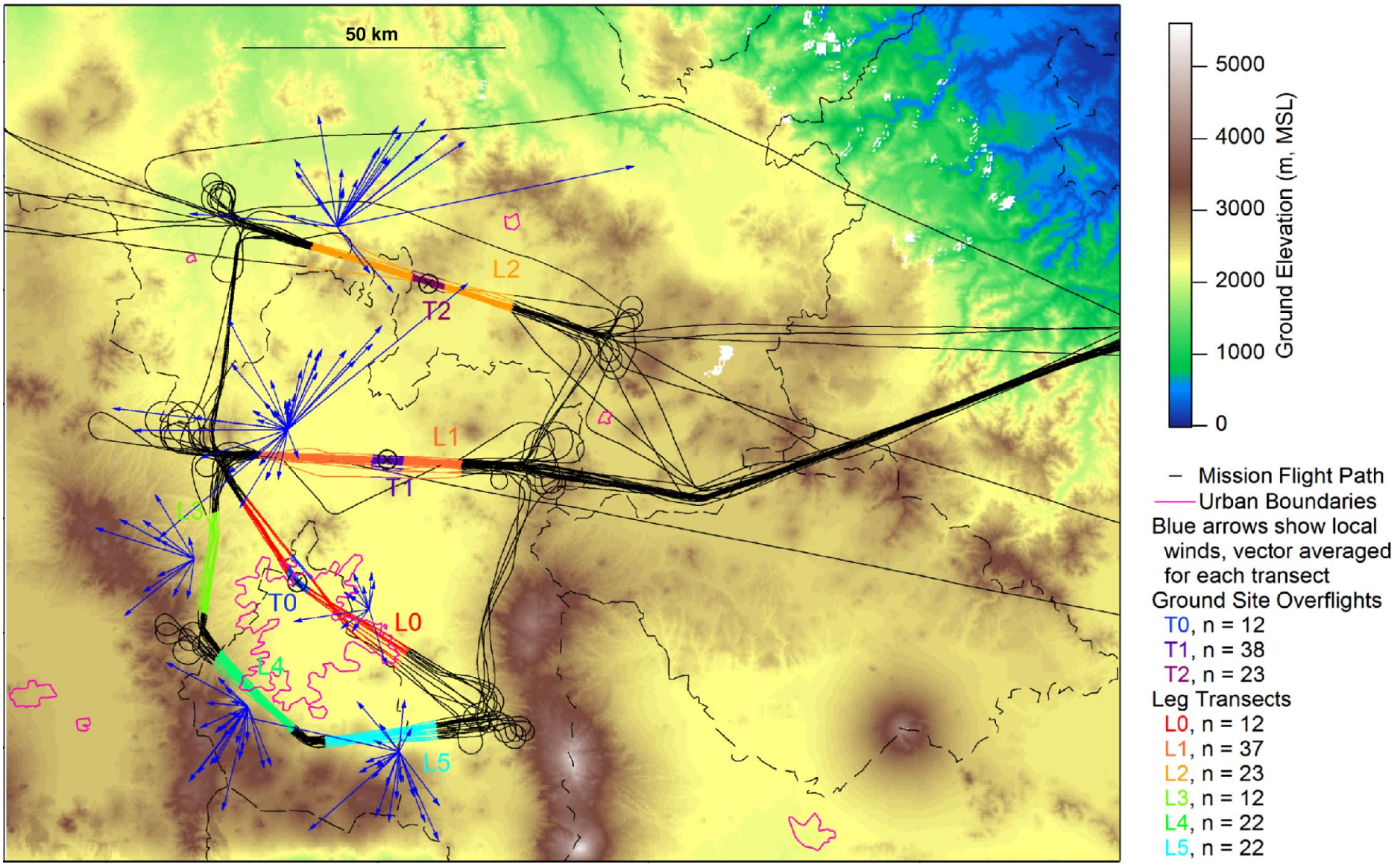
Chief scientist: Warren Wiscombe

ASD INVESTIGATORS AT FIELD PROJECT IN MEXICO, 2006

AIRCRAFT MEASUREMENTS

G-1 FLIGHT TRACKS DURING MAX-MEX

Composite of multiple flights during March, 2006

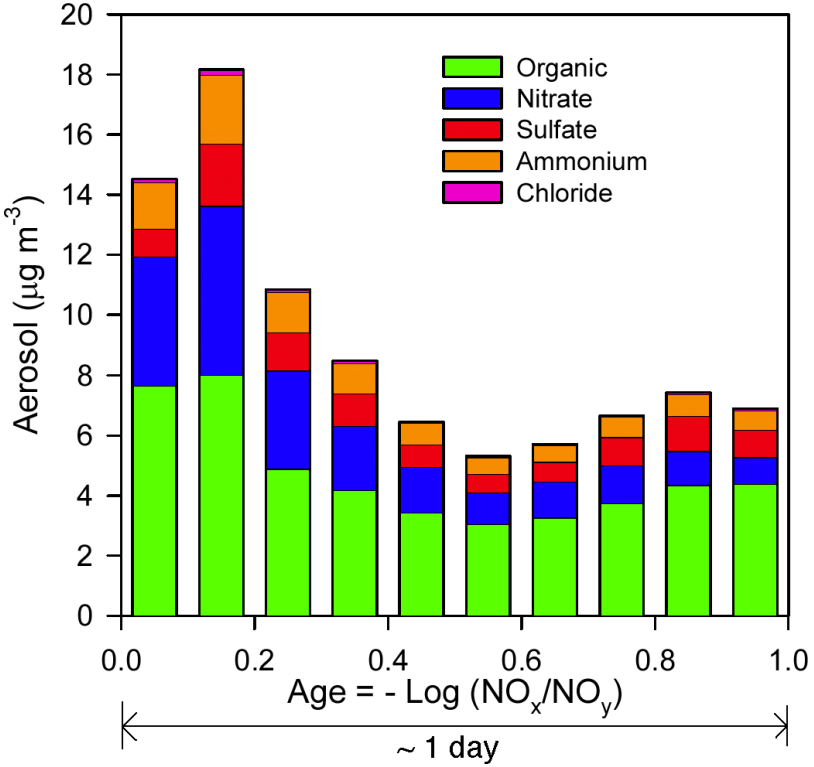


Transport distance and time increase from L0 to T1 to T2.

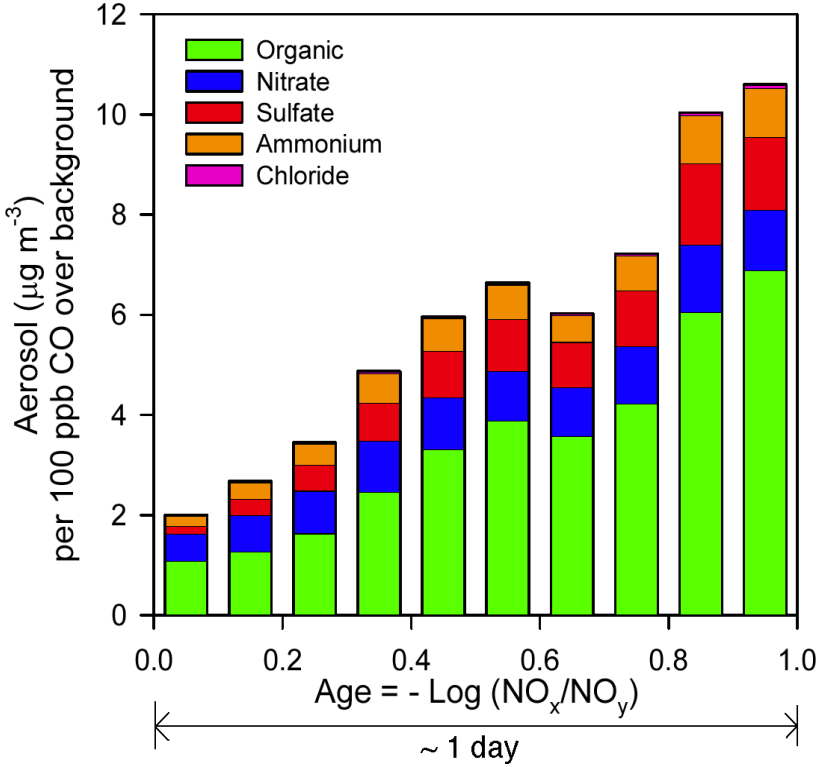
SECONDARY AEROSOL PRODUCTION

Parcel age measured using $-\log(NO_x/NO_y)$ as clock

Concentration



Normalized concentration



Dilution is accounted for by normalizing aerosol concentration to CO above background.

~5 × *increase* in total aerosol; **~7 × *increase*** in organic aerosol.

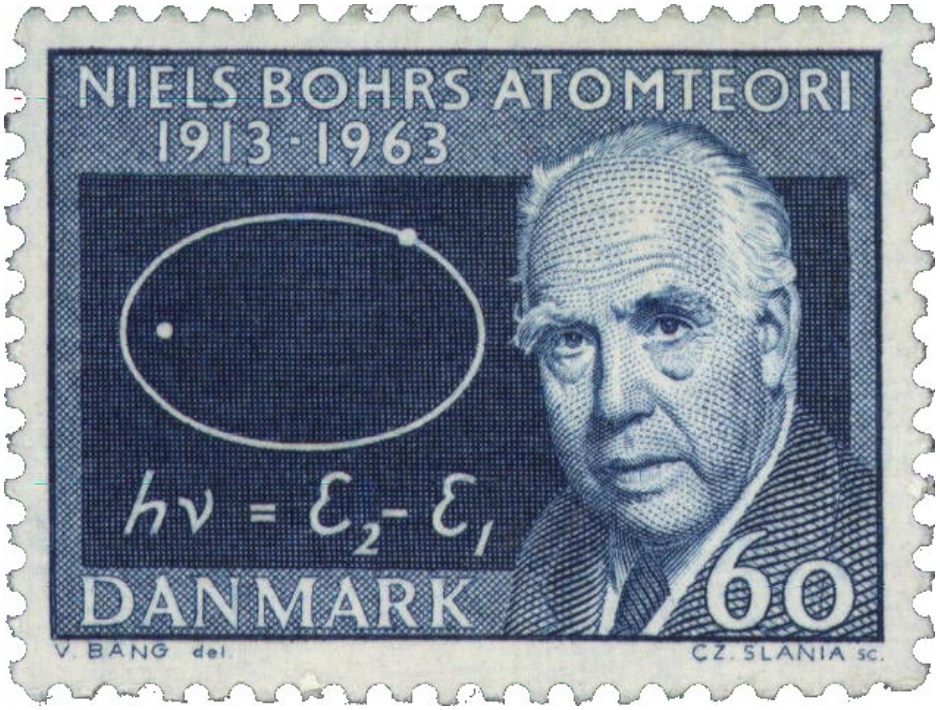
Measured increase in organic aerosol exceeds modeled based on laboratory experiments and measured volatile organic carbon ***tenfold***.

ARM MOBILE FACILITY

DEPLOYMENT IN NIAMEY, NIGER

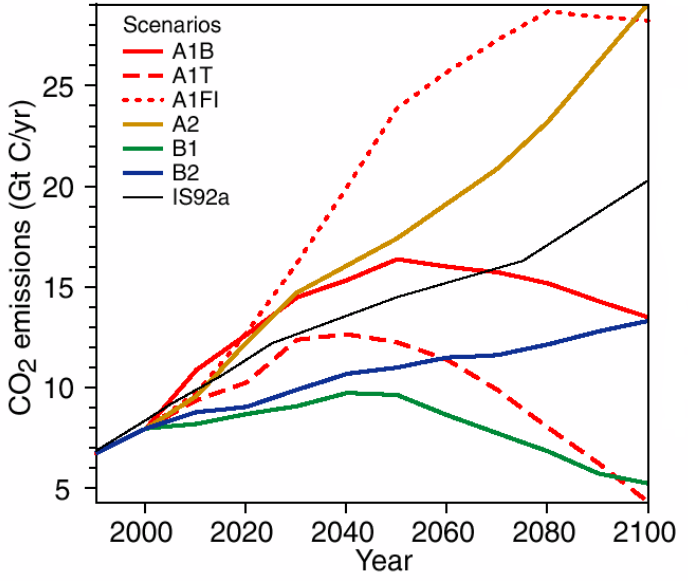
Looking to the Future . . .

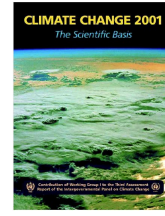
Prediction is difficult,
especially about the future.



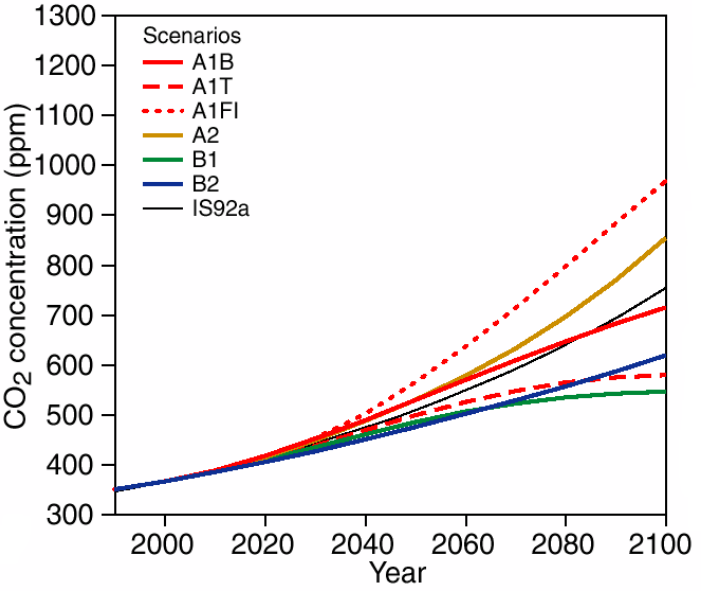
– Niels Bohr

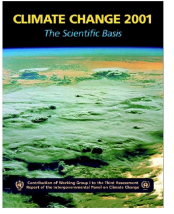
PROJECTIONS OF FUTURE CO2 EMISSIONS



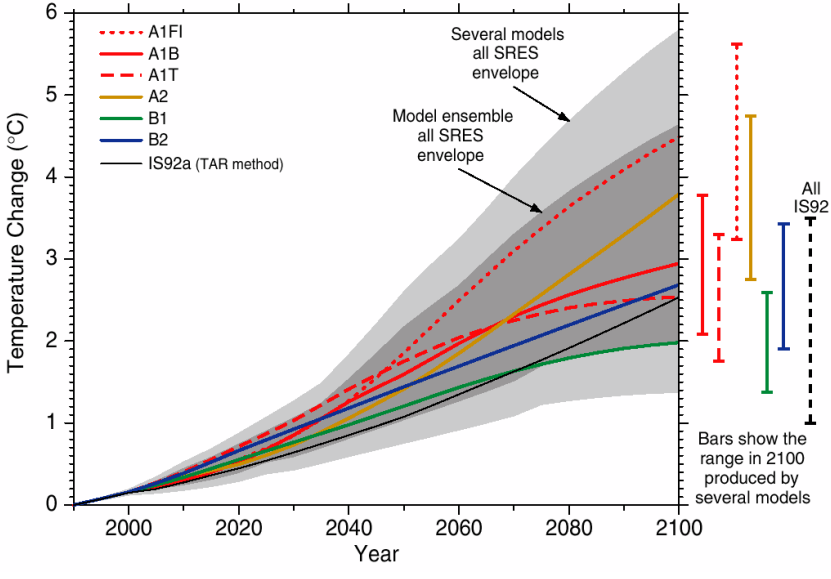


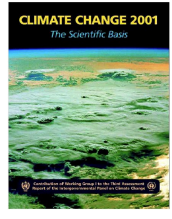
PROJECTIONS OF FUTURE CO2 CONCENTRATIONS





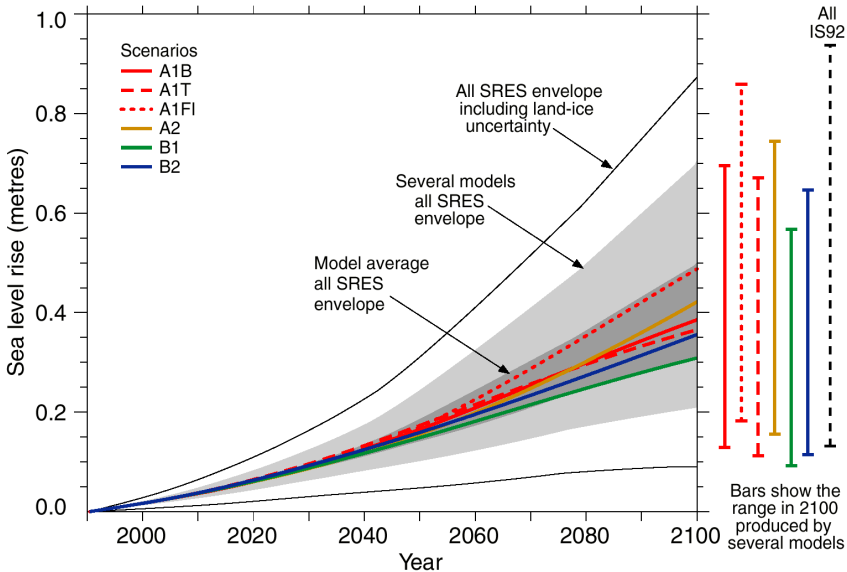
PROJECTIONS OF FUTURE TEMPERATURE CHANGE

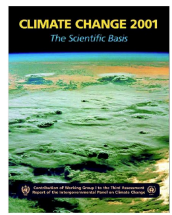




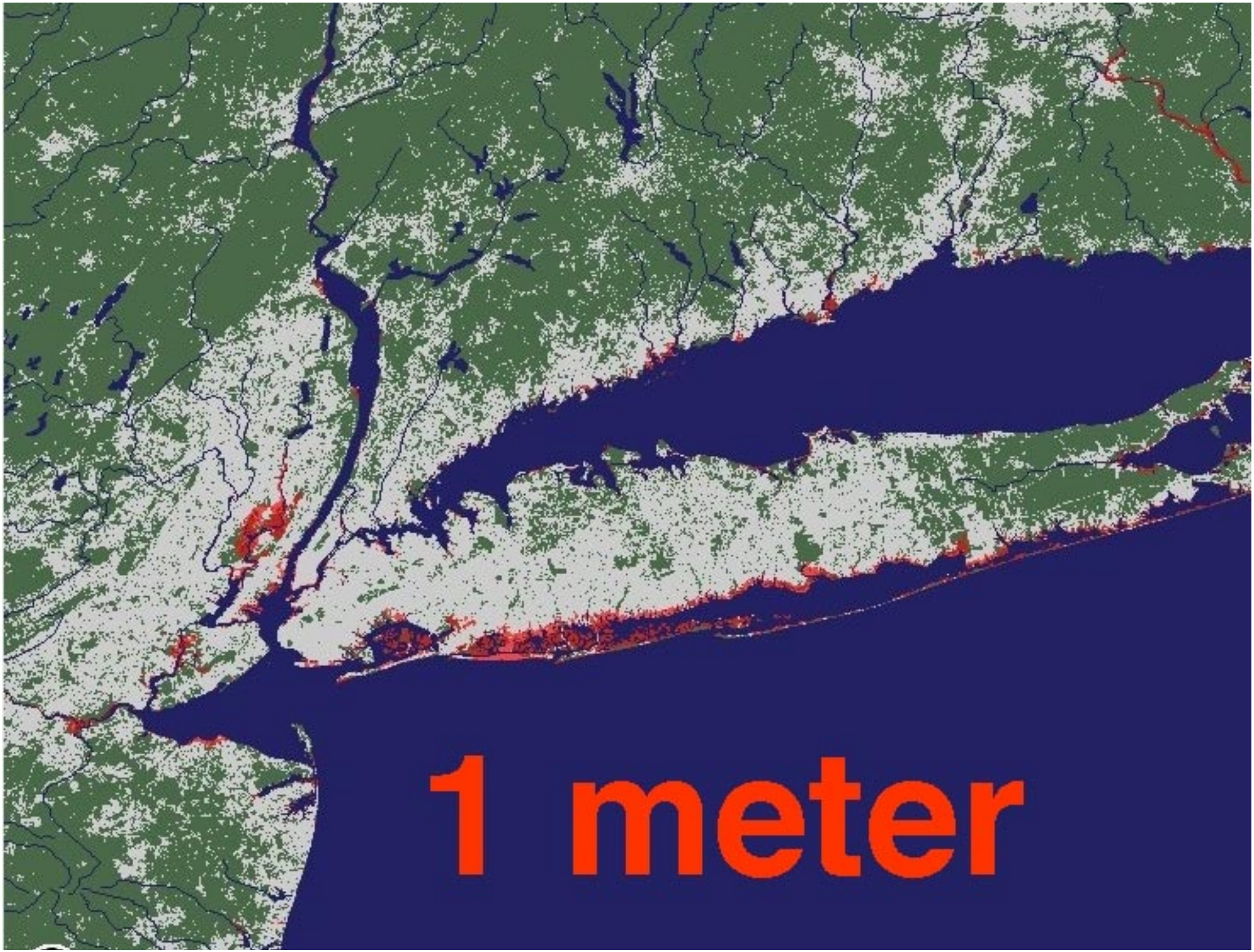
PROJECTIONS OF FUTURE SEA LEVEL RISE

Thermosteric (density change) only



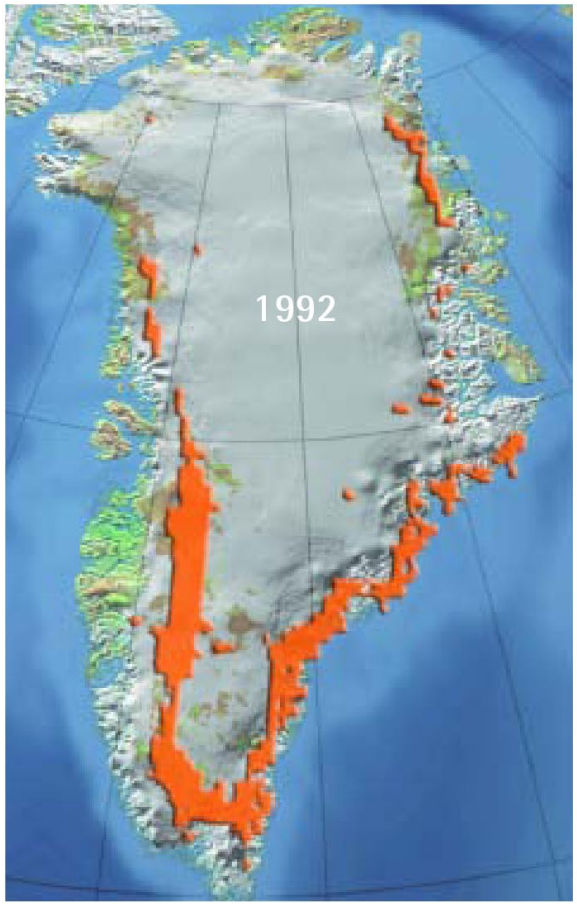


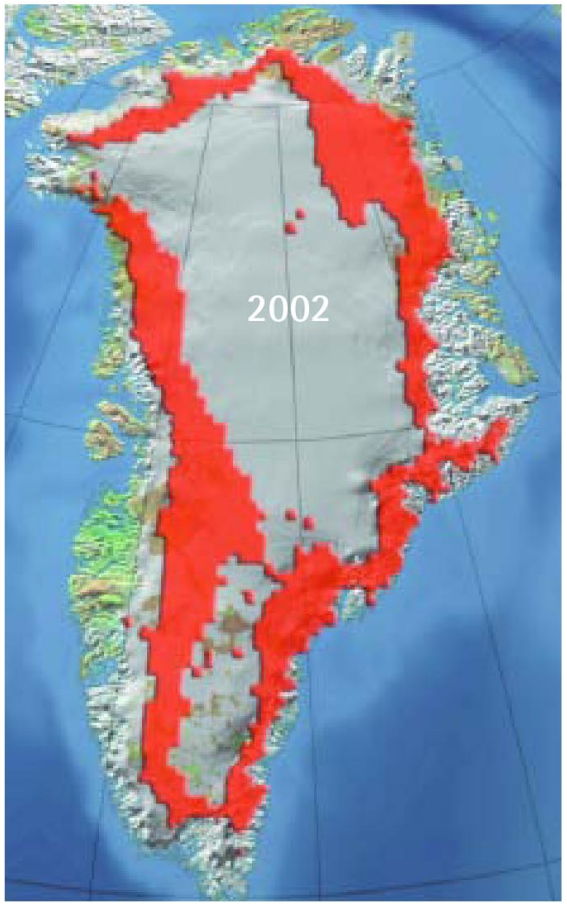

present


1 meter

MELTING OF GREENLAND ICE CAP

Satellite determination of extent of glacial ice 1992 vs 2002

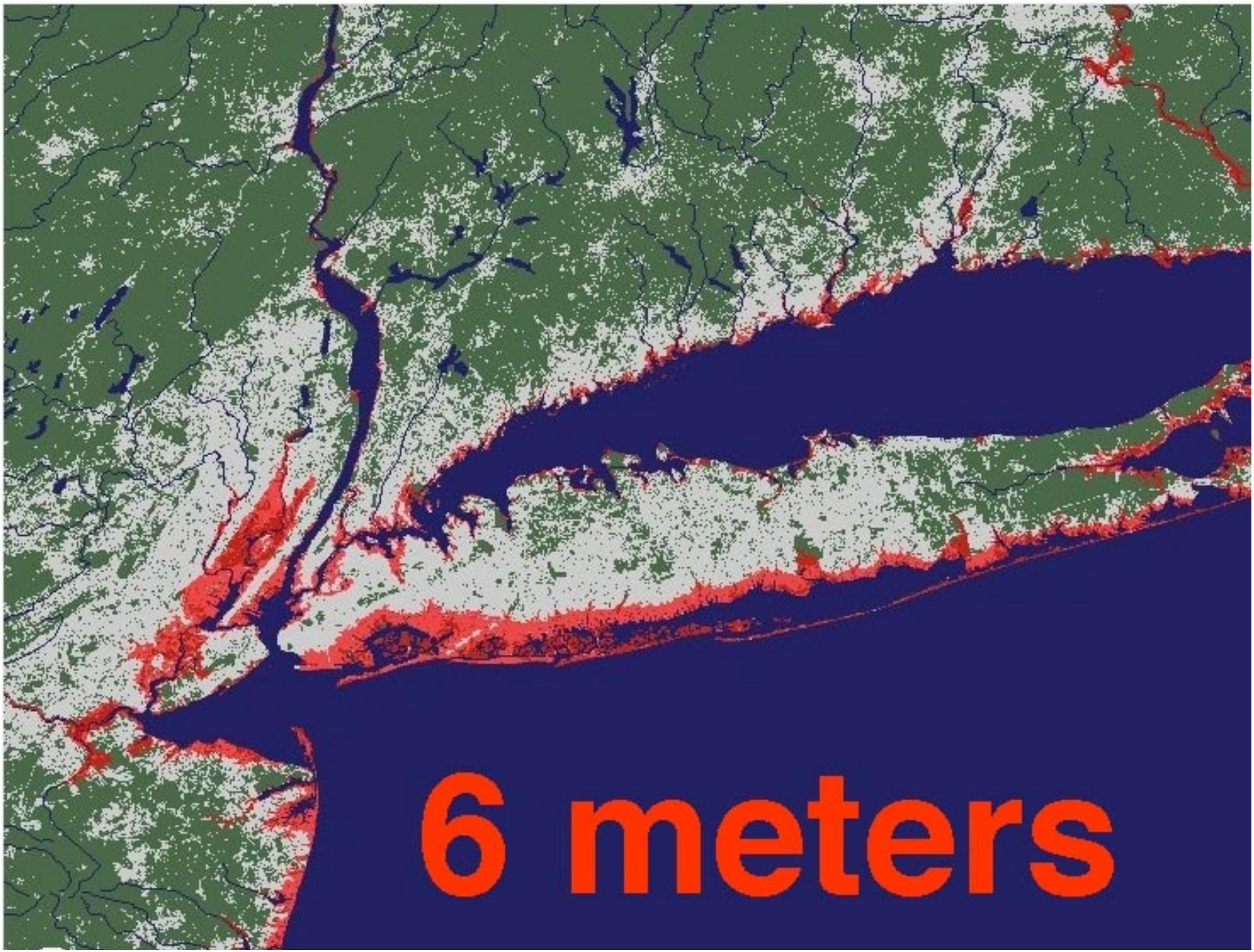




NASA

Arctic Climate Impact Assessment, Cambridge, 2004

Complete melt of the Greenland ice sheet would raise the level of the global ocean 7 meters.


6 meters

CONCLUDING REMARKS

Atmospheric carbon dioxide will continue to increase absent major changes in the world's energy economy.

The consequences of this increase are not well known but they range from ***serious*** to ***severe*** to ***catastrophic***.

Present scientific understanding is sufficient to permit "no regrets" decision making.

Research is urgently needed to refine "what if" projections.

Actions taken (or not taken) today will inevitably affect future generations.